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Integrating Renewables and Energy Efficiency: Smart Grid Innovation Trends

Liu Yang and Zhong Sheng

SYNOPSIS

The energy sector is undergoing a paradigm shift from a fossil fuel based system to a much more distributed system with increasing renewable energy capacity and improved energy efficiency. In this regard, new smart grid technologies are opening up tremendous opportunities for energy transition and greenhouse gas emissions reduction. This policy brief provides an overview on the main features and innovation trends of smart grid technologies over the 1919 – 2016 period. It also examines the implications of these developments for energy companies, users, and policy-makers.

KEY POINTS

- The greatest transformational potential for the smart grid revolution is its ability to enable demand-side management, incorporate distributed energy resources, maximise the penetration of renewable energy, and couple transport and electricity.
- Smart grid innovation has been concentrated on two fields, namely, demand-side management, and transmission and distribution. Together these two account for 82 per cent patented technologies.
- 95 per cent of patented technologies are invented by ten countries, led by China, Japan, and the US. China, South Korea and Taiwan are latecomers with the average year of their patents being reported from 2009 onwards.
- As disruptive smart grid technologies redefine the interaction of consumers with energy suppliers, a well-structured regulatory reform process will be needed to enable new business models that monetise the benefits and costs across the new value chains.

INTRODUCTION

The global electricity grid is one of the most complex infrastructure with 50 million kilometres of network cables installed across the world. Traditionally, central grids are built with a simple purpose – namely to deliver electricity from large-scale power plants to end-users, with little requirement for demand-side management. Today, the function of grids is undergoing a paradigm shift, towards a digitally enhanced, multi-directional and integrated system.

Smart grid technologies encompass a wide range of digital-based hardware and software technologies, which are used to support the penetration of renewables and distributed generating sources such as solar photovoltaics, battery storage, demand response and electric vehicles. While the definition of what a "smart grid" constitutes varies across and within countries, smart grids typically feature a range of common characteristics. They consist of the increased use of digital information and control technologies, smart transmission, incorporation of demand-side management and energy efficiency, advanced metering infrastructure and distribution automation, as well as the integration of storage and peak-shaving technologies such as electric vehicles. In sum, smart grid technologies present a unique opportunity for the adopters to leapfrog to a more efficient energy system as a whole.

The transformation of smart grids in each country and region has a unique set of characteristics. The European Union (EU) seeks to replace at least 80 per cent of electricity meters with smart devices by 2020 and put consumers at the centre of the new energy system through the *Clean Energy for All Europeans* package. The United States of America (US) has *Grid 2030* with the National Electric Delivery Technologies Roadmap. China promotes the global electricity interconnection initiative, which aims to extend a globally interconnected smart grid with ultra-high voltage grid. Germany has the *Digital Agenda for the Energy Transition* to integrate the high share of renewables. The *Japan Smart Community Alliance* promotes innovative energy and social infrastructure in Japan. South Korea places the fourth industrial revolution on the top of the new government's agenda. Australia trials smart meters, peak and off-peak pricing, and remote switching in its "Solar Cities" programme. The following section explains the benefits of utilising smart grid technologies.

ANALYSIS

Enabling Demand-Side Management

Today, networked and demand response-enabling devices are permeating many aspects of daily life. This increasing connectivity generates a great amount of data, providing a strong tool for delivering system-wide energy savings. The average cost of a smart meter has dropped by about one-quarter since 2008, with nearly 600 million smart meters being deployed globally as of 2016. According to the 2017 International Energy Agency (IEA) report on *Digitization and Energy*, it is estimated that by 2040, 1 billion households and 11 billion smart appliances could actively participate in interconnected electricity systems across the world. Combined with the increased use of digital sensors and control equipment, these smart appliances can be connected to a network and controlled remotely. Smart grid technologies allow consumers to respond to market signals and shift consumption to off-peak hours with a surplus of electricity supply. The IEA report suggests that the implementation of the full technical potential of demand response could provide 185 GW of system flexibility in 2040, which is comparable to the currently installed electricity supply capacity of Italy and Australia combined. This could save US$270 billion of investment in new electricity infrastructure that would otherwise be needed to ensure the security of supply.

Incorporating Distributed Energy Resources

Smart grid technologies enable the energy system to become more decentralised, with distributed generation providing an integrated suite of energy services in a clean and customised manner. Distributed energy systems typically offer multi-generation of electricity, cooling, heating, hot water, drying, and steam, providing the efficiency performance as high as 70 to 90 per cent. Distributed energy systems can also ensure cascade energy usage, by using high-grade energy for power generation, and low-grade energy for cooling and heating services. In addition, the network loss typically represents about 6.6 per cent of power generation in the centralised transmission and distribution system. Distributed energy can significantly reduce energy loss because short-distance transportation improves the overall efficiency of energy supply.

At the aggregate level, a large number of distributed generation systems can become a virtual power plant, being able to dispatch power to the grid to be traded at wholesale pool prices. Consumers become "prosumers", as they have the choice of buying electricity from a retailer, or producing and selling part of the electricity themselves. In addition, technology costs of solar panels and storage are falling more quickly than expected. Over the last decade, the unit cost of small-scale PV has dropped by a factor of five, and battery storage by more than two-thirds. The combination of distributed generation based on renewable energy and storage units now offer an economically attractive solution for access to electricity in remote areas and developing countries; thus significantly reducing the amount of CO_2 generated through the use of fossil fuel.

Maximizing Penetration of Renewable Energy

The EU and countries like China have shown concern regarding the implications of high penetration of renewable energy on grid stability. In this regard, smart and distributed loads can unlock the flexibility of the central grid to drastically reduce curtailments of variable renewables, thereby enhancing their share of power generation while mitigating CO_2 emissions. According to the 2017 IEA report, more than one-quarter of global electricity will have to be generated by wind and solar by 2040 in order to meet the global 2 degrees climate target. In the case of the EU, renewables are expected to make up more than 60 per cent of total electricity generation in 2040, which is more than double today's level. Flexibility measures supported by demand response and storage technologies can allow the EU system to accommodate 67 TWh of additional generation from renewables and to avoid about 30 Mt of CO2 emissions.

Coupling Transport and Electricity

Smart grid technologies will enable the coordination of electric vehicle (EV) charging. In an IEA scenario where 150 million EVs are deployed globally by 2040, the capacity needs for standard EV charging could reach 140 GW in 2040. As EVs represent mobile demand for electricity, shifting the charging of EVs to periods when electricity demand is low could deliver significant system savings. Smart charging infrastructure can reduce peak demand from EV charging by at least 65 GW and result in system savings of US$100 billion in 2040. Furthermore, potential vehicle-to-grid technologies that allow bi-directional charging could turn EVs into mobile batteries, thus unlocking further flexibility to the grid.

Tracking Smart Grid Innovation Trends

To track smart grid innovation trends, we constructed a complete patent dataset for smart grid technologies related to climate change mitigation based on the Worldwide Patent Statistical Database (PATSTAT) developed by the European Patent Office. The data of patent applications as outcomes of R&D investments provides a suitable indicator for tracking and assessing global innovation progress.

A total of 11,546 patent families are identified in the field of smart grid technologies related to climate change mitigation from 1919 to 2016, with roughly 8.5 per cent of total patent families filed in the period up to 1990. Since 2005, there has been an exponential growth in the number of patent families in this field. Patent applications reached a peak in 2014, with 1,509 technologies registered that year alone. The number of patent families dropped in 2015 for the first time since 2005, probably because innovation in this field has temporarily reached a plateau, or simply because of the lag caused by data collection.

With respect to the technological characteristics of the patents, the innovation activities over the entire period under research in the smart grid field is concentrated in two major areas – demand-side management (9,998 patent families), and transmission and distribution (2,234 patent families) – which together account for 82 per cent of all the patented technologies. In particular, demand-side management is the most concentrated area, accounting for 67 per cent of all the technologies. EV and distributed generation technologies have almost equal shares – 9 per cent and 8 per cent, respectively. Patents for storage technology are still limited, representing just 1 per cent of the patents pool.

Overall, 64 countries are involved in the smart grid patents applications. The top 10 countries, led by China, Japan and the US, hold around 95 per cent of all these patented technologies. Three countries, China, Japan and the US, have more than 1,000 patent families, which together account for about 79 per cent of total patents. China has contributed to the most number of patent families (5,203), while Japan and the US have 2,642 and 1,459 patent families, respectively. To reflect technology adoption levels, China, Japan and the US are the top three patent authorities where smart grid technologies are filed.

Latecomer countries have greatly contributed to smart grid innovation. The average of filing years for all global patents in our dataset is about 2007. The oldest patent dates back to 1919 in France. The majority of patents that have been filed are less than 10 years. China, South Korea and Taiwan can be characterised as latecomers, as the average years of their patents are reported from 2009 onwards. Meanwhile, most of patents filed by China took place from 2013 onwards. This reflects the leapfrogging opportunities brought by smart grid and digitalisation technologies for these fast growing economies. Global R&D collaboration on smart grid technologies represents merely 4.5 per cent of all these patented technologies, more than half of joint ownership of the patents are concentrated among the US and a few developed countries.

The Future Ecosystem of Smart Grid

The greatest transformational potential for the smart grid revolution is its ability to blur the distinction between supply and demand, and to enable interaction with consumers to balance demand with supply in real time. New business models of future utilities will shift towards supplying energy services beyond energy as a commodity. The ability of linking and aggregating large numbers of end-use devices and assets will become a key competitive advantage.

The success of future market leaders will depend on the extent to which they can upscale the exchange of these services among massive consumers. Innovative businesses can exploit opportunities to create value in a more customer-oriented and service-based approach. End users will be empowered to adopt smarter, cleaner technologies that help save money on utility bills. New energy trading opportunities enabled by the latest technologies such as blockchain can turn consumers into prosumers. The adoption of EVs and storage will add a substantial amount of intelligent electrical load to the power system. This in turn opens up opportunities for large-scale smart demand response, leading to increasing the system flexibility and penetration of variable renewables.

CONCLUSION

Innovative technologies and policy frameworks will continue to evolve. In order to make the most of smart grid technologies, a framework of integrated policy, market design and business models to optimise renewables and energy efficiency is needed. Smart grid technologies will transform the way our electricity supply functions. Currently, most countries are in the early stages of formulating regulatory policies for the function of smart grids. As smart grid technologies develop, policy and regulatory changes are set to accelerate in the years to come. Both transmission and distribution network operators will have to strengthen cooperation and data exchange.

As disruptive smart grid technologies redefine the interaction of consumers with energy suppliers, a well-structured regulatory reform process will be needed to enable new business models that monetise the benefits and costs across the new value chains. Policy coordination across countries will also be fundamental to unlocking the full potential of digitalisation, and in ensuring a proper functioning of smart grids following increased connectivity in the electricity markets.

WHAT TO LOOK OUT FOR

- New regulation to reflect the flexible values of distributed generation resources including solar PV, storage and EVs.
- New incentives to materialise demand response and energy efficiency programmes through market-based instruments, such as capacity markets and auctions.
- New business ecosystems and updated policy frameworks to encourage innovative business models that help to realise the full potential of smart grid technologies.

Liu Yang, PhD is a Senior Research Fellow at the Energy Studies Institute, National University of Singapore.
Zhong Sheng, PhD is a Research Fellow at the Energy Studies Institute, National University of Singapore.

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